Convective Gravity Waves during the North American Thunderstorm Season

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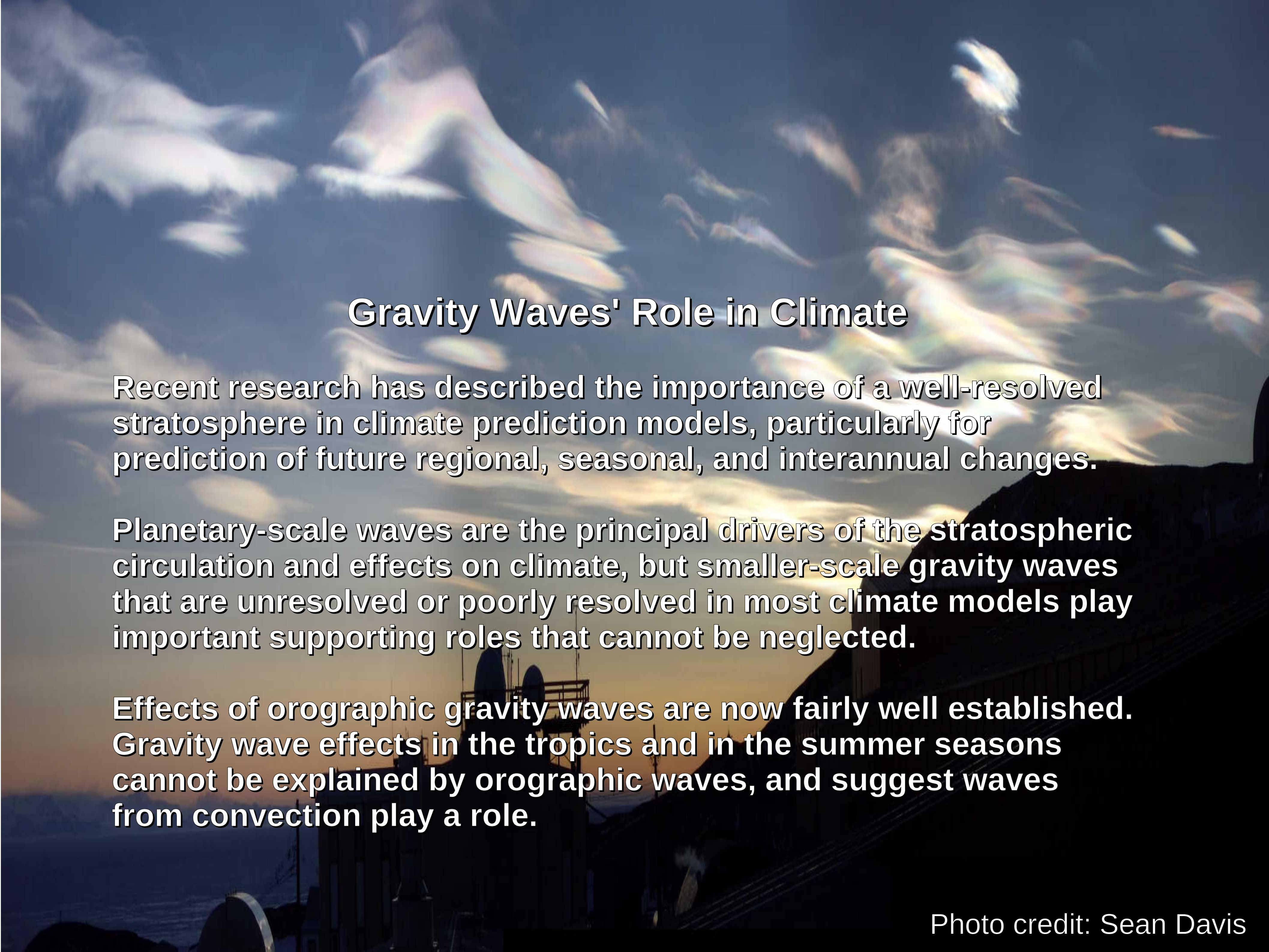
Forschungszentrum Juelich

Reference:

Hoffmann, L. and M.J. Alexander, 2010: Occurrence frequency of convective gravity waves during the North American thunderstorm season. *J. Geophys. Res.*, **115**, D2011, doi:10.1029/2010JD014401.



Gravity Waves' Role in Climate

Recent research has described the importance of a well-resolved stratosphere in climate prediction models, particularly for prediction of future regional, seasonal, and interannual changes.

Planetary-scale waves are the principal drivers of the stratospheric circulation and effects on climate, but smaller-scale gravity waves that are unresolved or poorly resolved in most climate models play important supporting roles that cannot be neglected.

Effects of orographic gravity waves are now fairly well established. Gravity wave effects in the tropics and in the summer seasons cannot be explained by orographic waves, and suggest waves from convection play a role.

Photo credit: Sean Davis

Gravity Waves in High-Resolution Climate Models

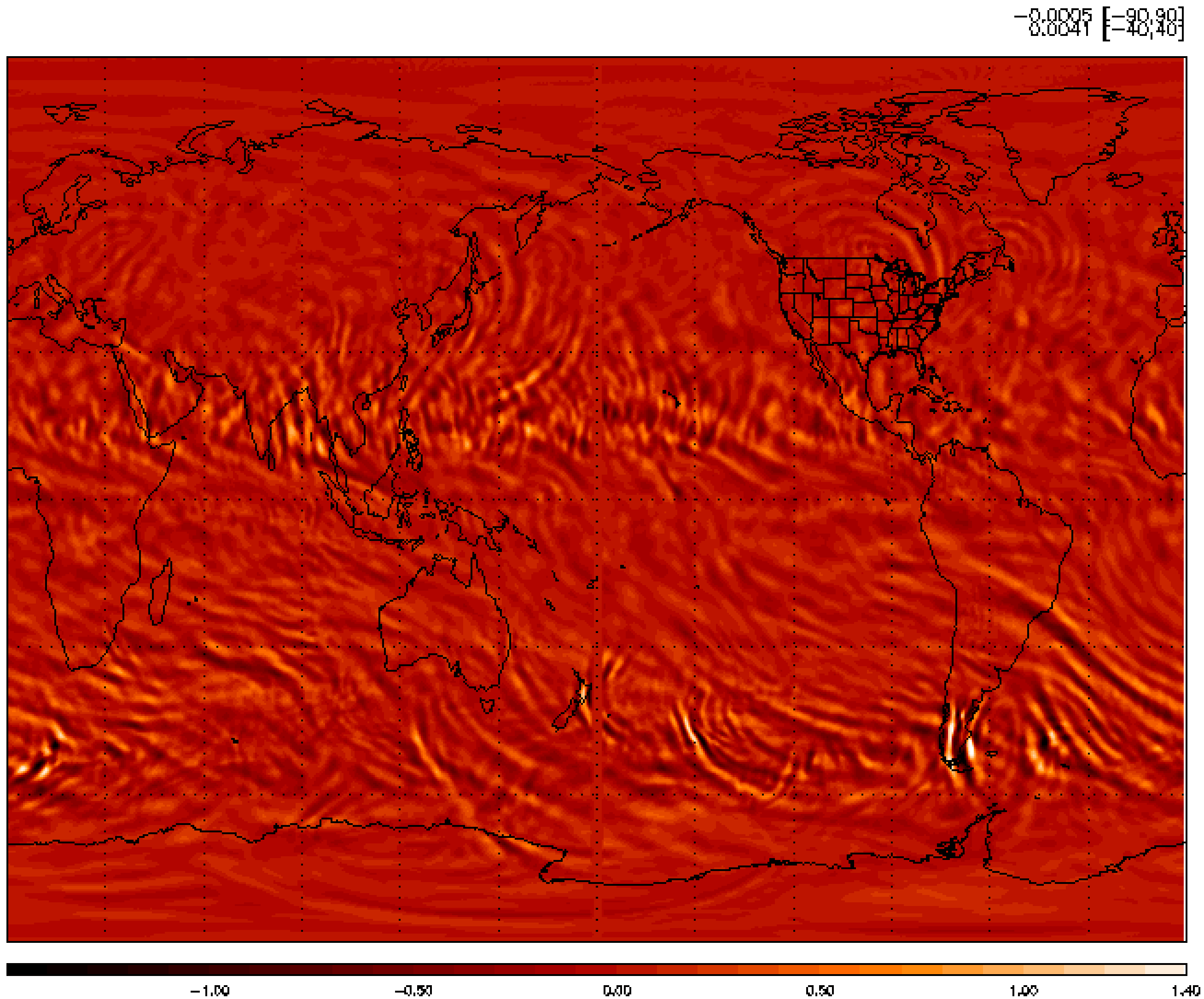
Resolution in climate models is improving:
AR4 ~ 2^{o}
AR5 < 1^{o}

Many gravity waves can be resolved at these resolutions.

Difficulties remain:

-- Gravity wave momentum flux spectrum is very shallow.

-- Many gravity wave sources remain unresolved.



0.5^{o}x0.5^{o} temperature fluctuations from MERRA (courtesy of Julio Bacmeister)

Gravity Wave Effects in Global Climate Models

Implementation of a gravity wave source spectrum parameterization dependent on the properties of convection in the Whole Atmosphere Community Climate Model (WACCM)

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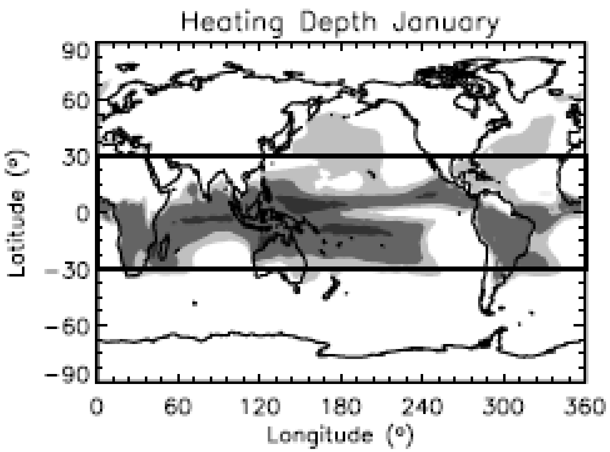
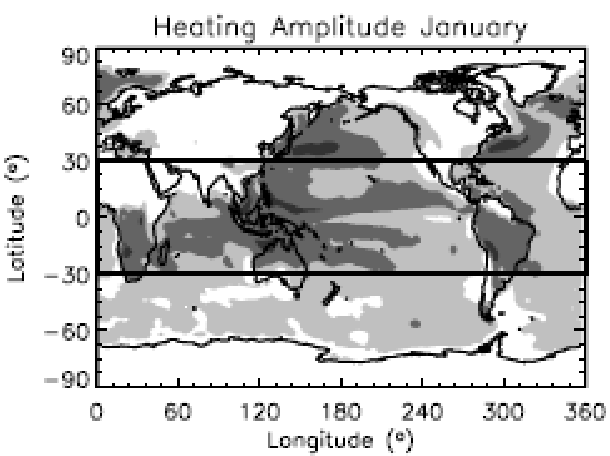
Advanced Study Program, National Center for Atmospheric Research, Boulder, Colorado, USA

Gravity waves provide a force on the mean flow that is treated with a parameterization in global climate models.

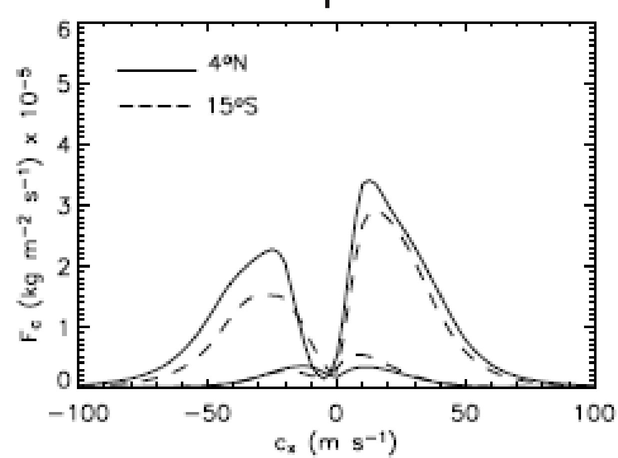
Recent work tries to include specific wave sources: Topography, fronts, and convection. [Richter et al. 2005; 2010]



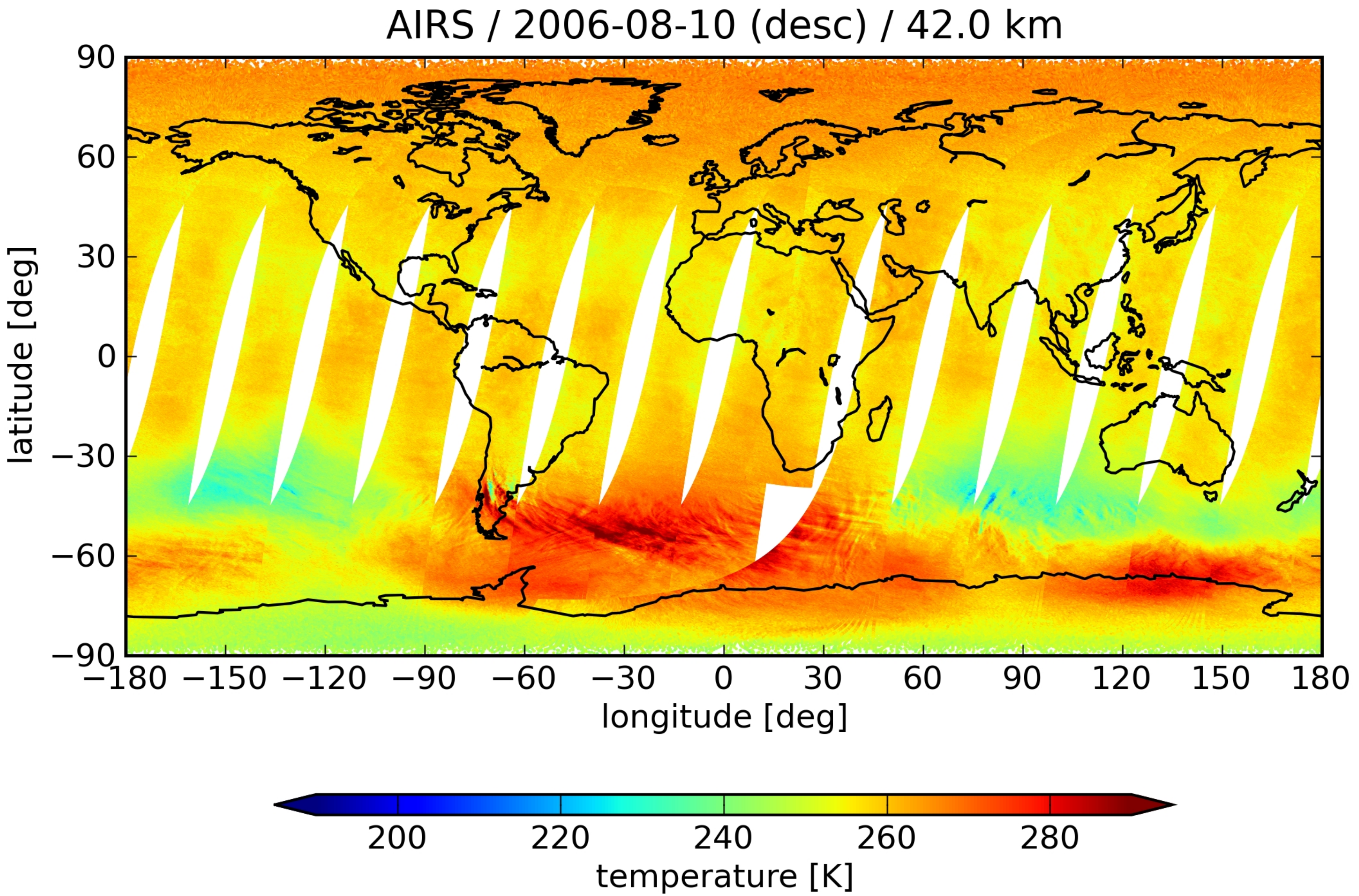


Use properties of the convection in the climate model to predict the spectrum of waves generated.

Wave Spectrum

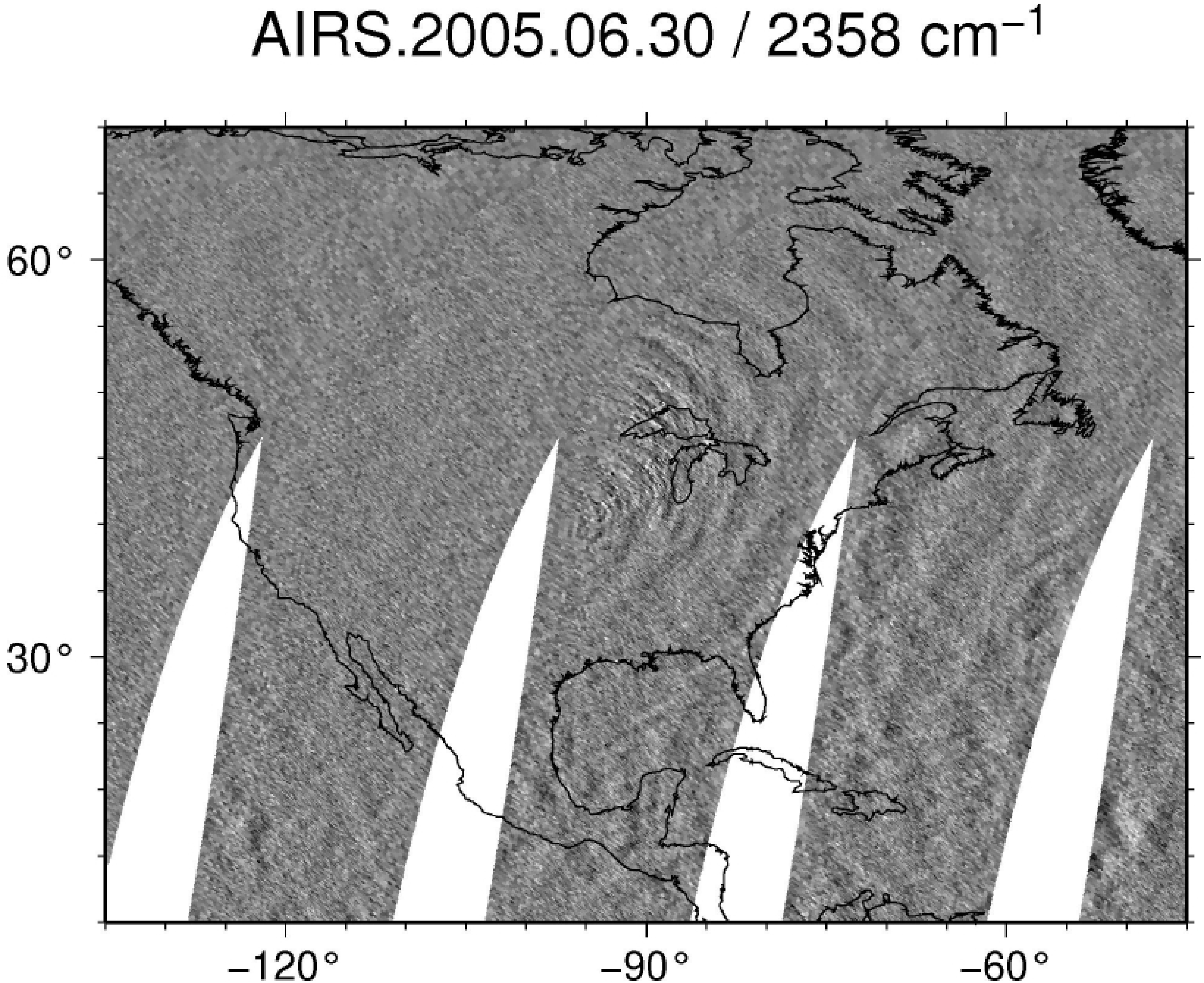


AIRS Full-Resolution Stratospheric Temperature Retrieval



Hoffmann & Alexander [2009]

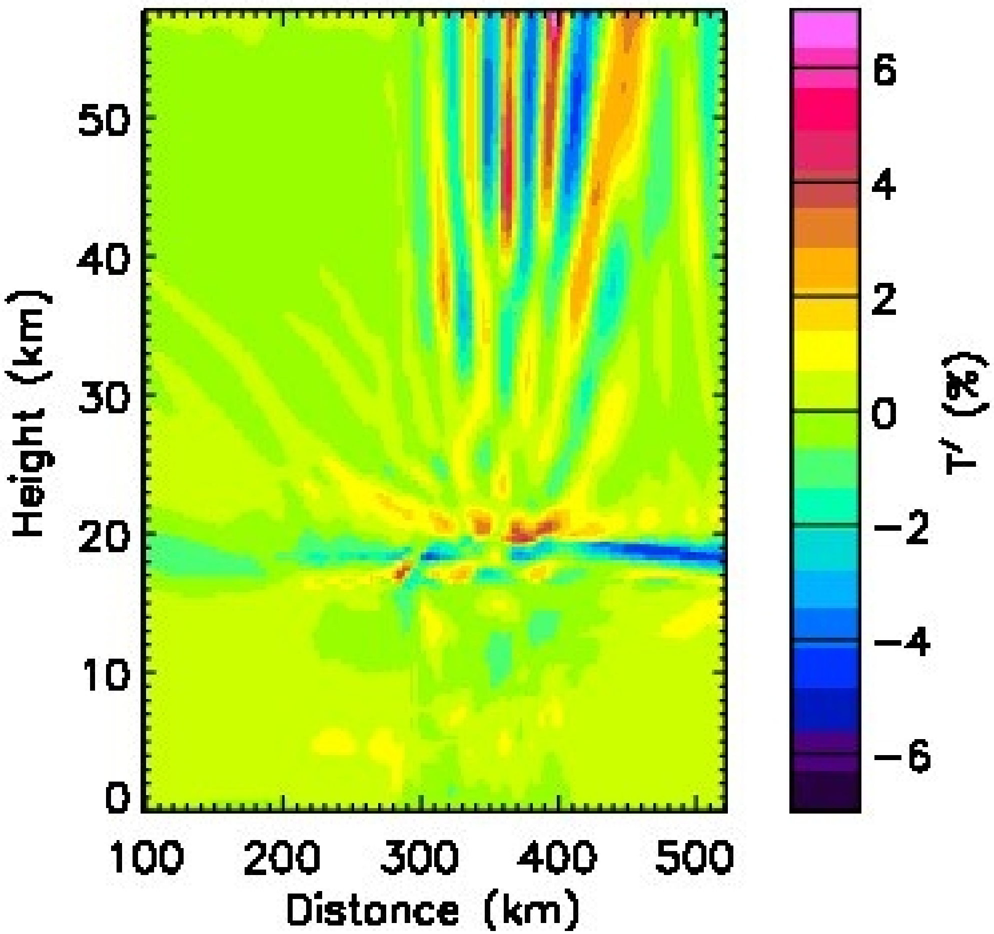
AIRS Brightness Temperatures: North American Summer

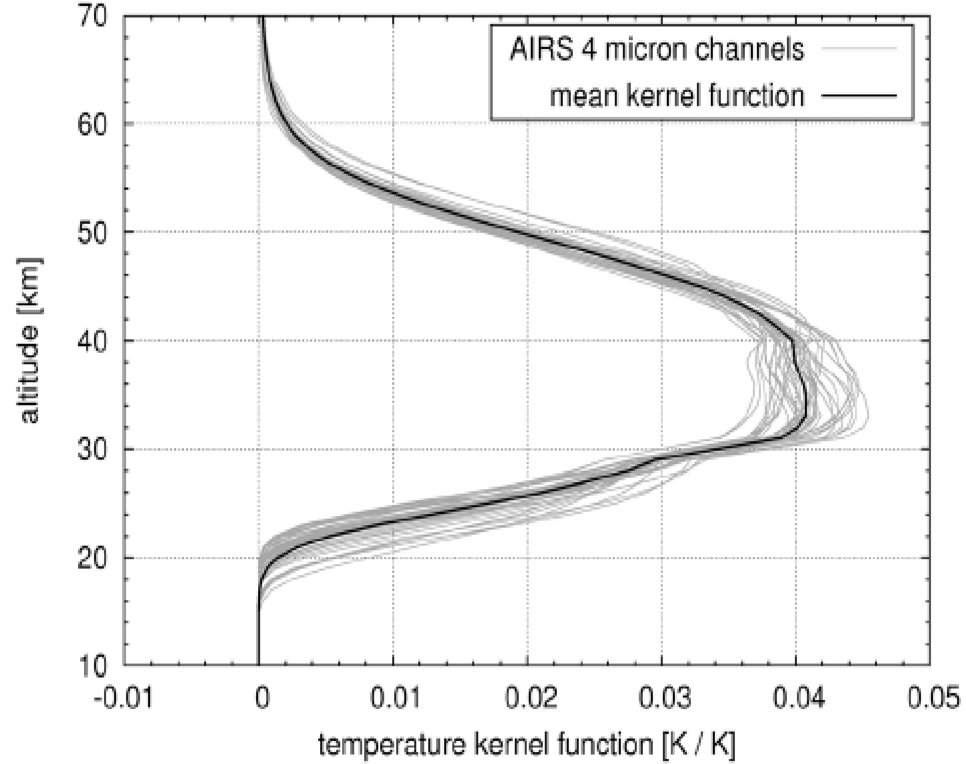


Gravity Waves Visible in AIRS

These have long vertical wavelengths > 12 km.
AIRS weighting functions eliminate shorter vertical wavelength waves.

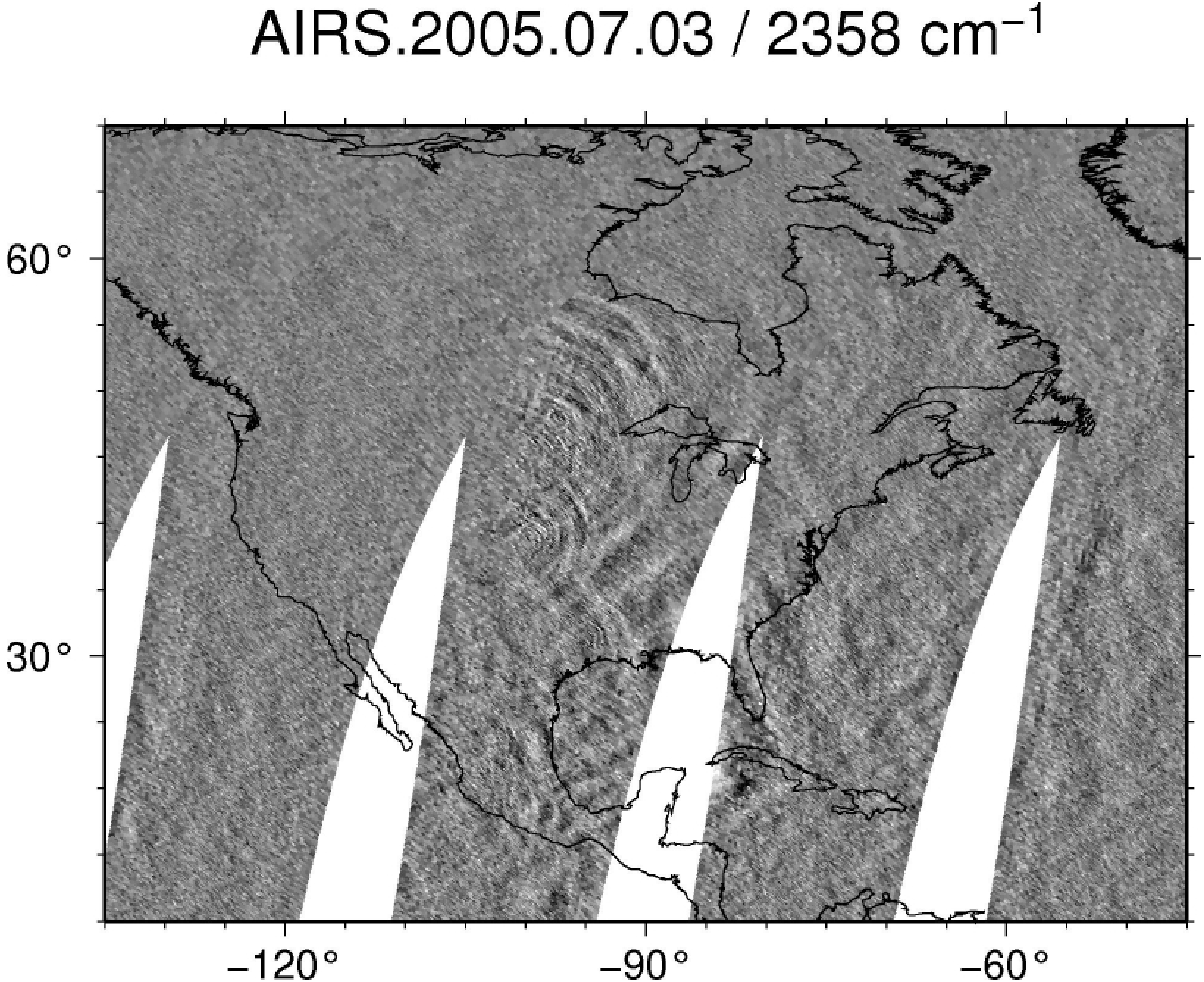
Sample x-section of modeled waves above convection



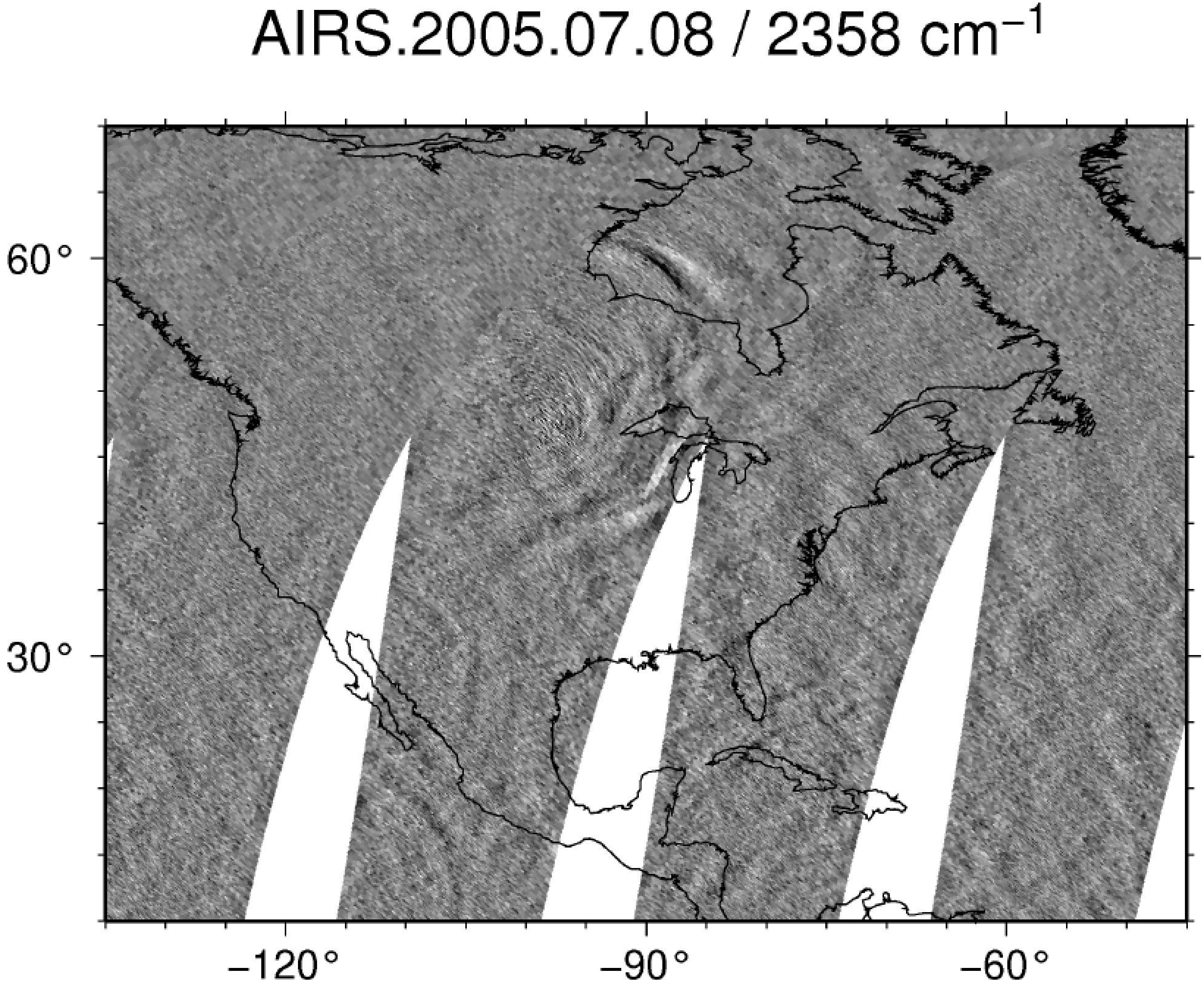


For this study, radiances from 42 AIRS channels are averaged to reduce noise and enhance signal from waves above convection.

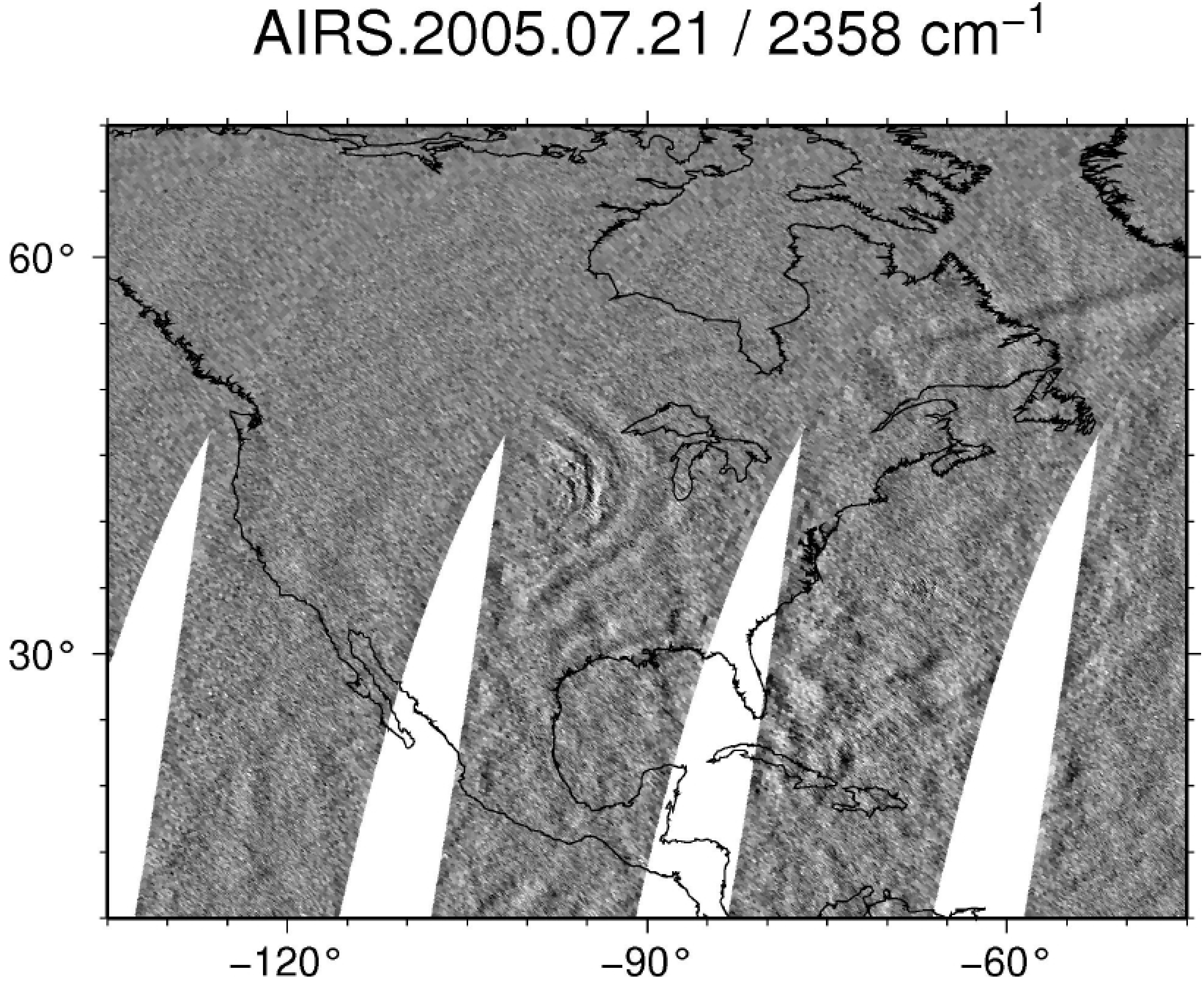
AIRS Brightness Temperatures: North American Summer



AIRS Brightness Temperatures: North American Summer

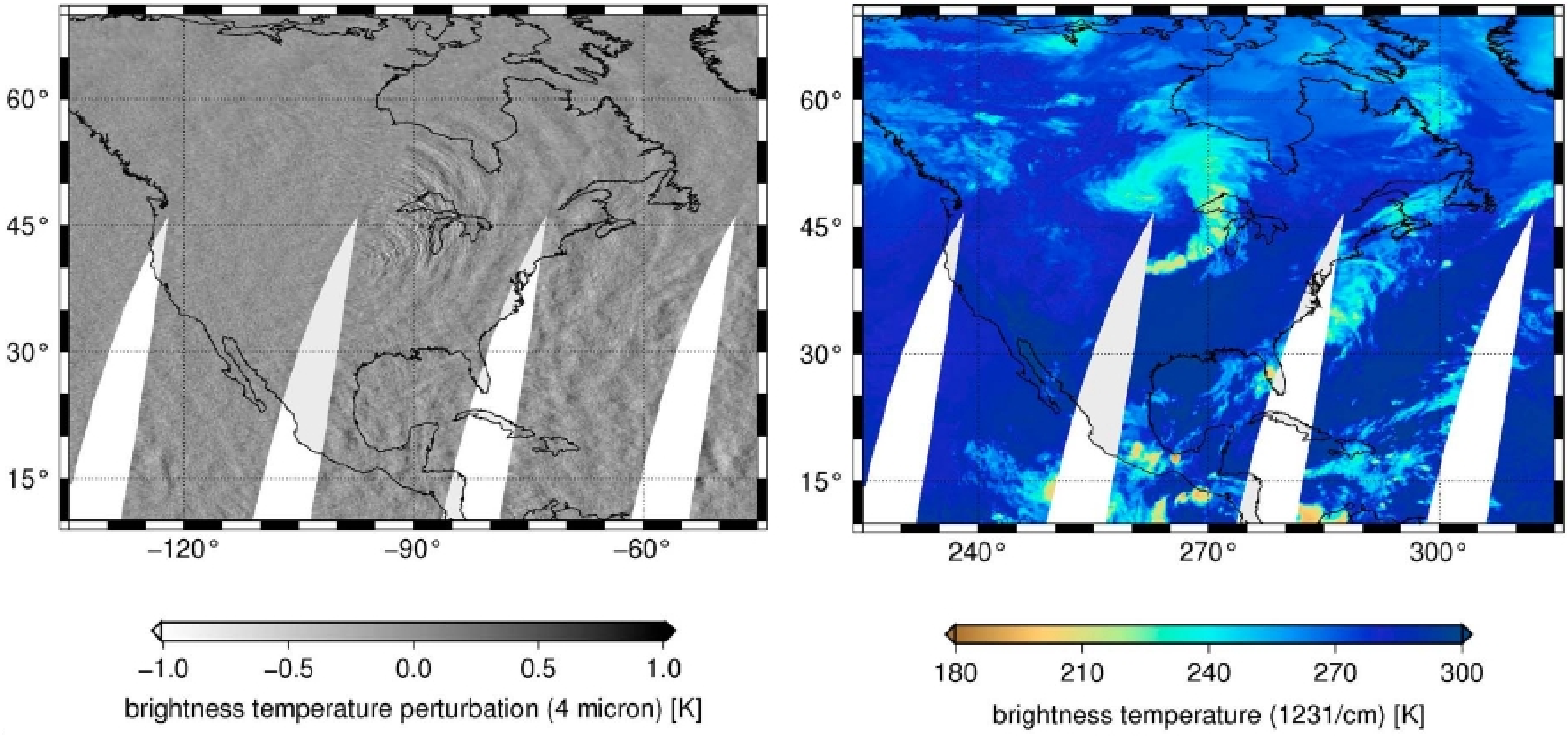


AIRS Brightness Temperatures: North American Summer



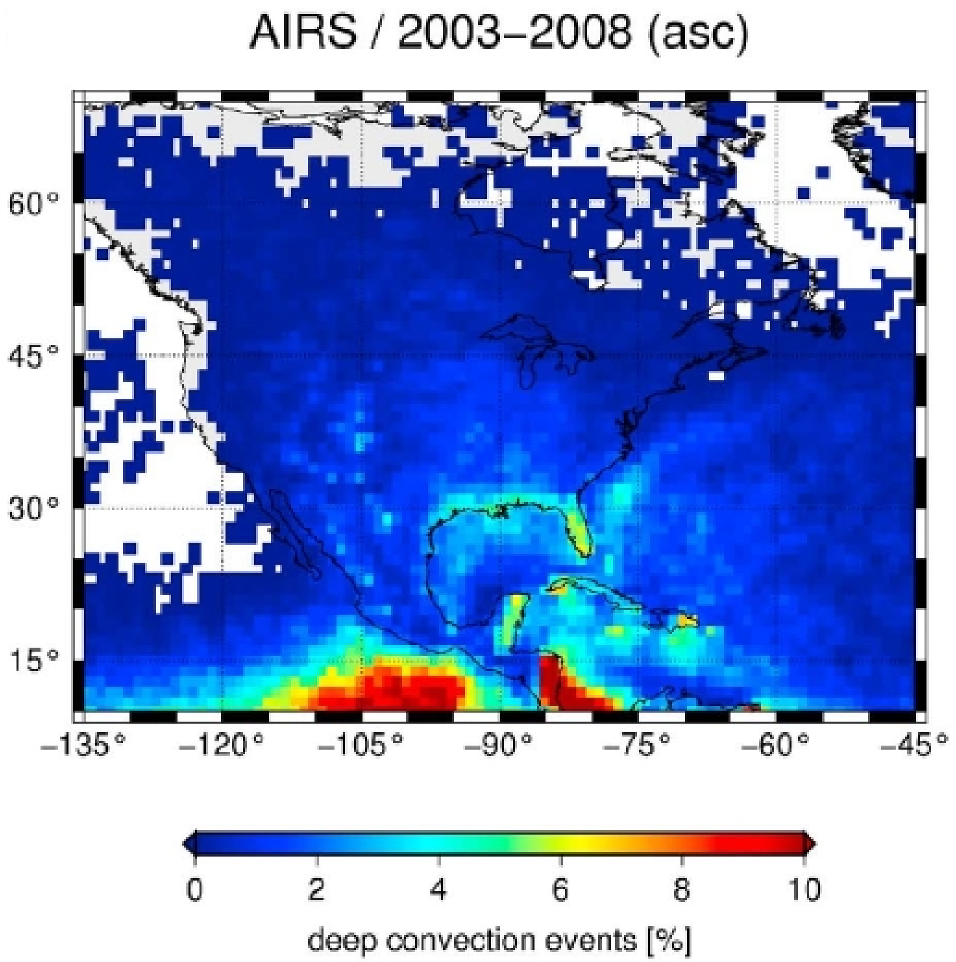
AIRS Cloud Channel Radiances (1231 cm^{-1})
provide coincident measure of deep convection

- Use T_B < 220 K as threshold for deep convection events
(e.g. Maddox [1980] definition for Mesoscale Convective Complexes)
- T=220 K occurs at ~ 12 km altitude at summer midlatitudes



Occurrence Frequency of Deep Convection Events

- Average May-August Great Plains thunderstorm season
- Six years of data 2003-2008
- Ascending data = daytime ~1:30pm



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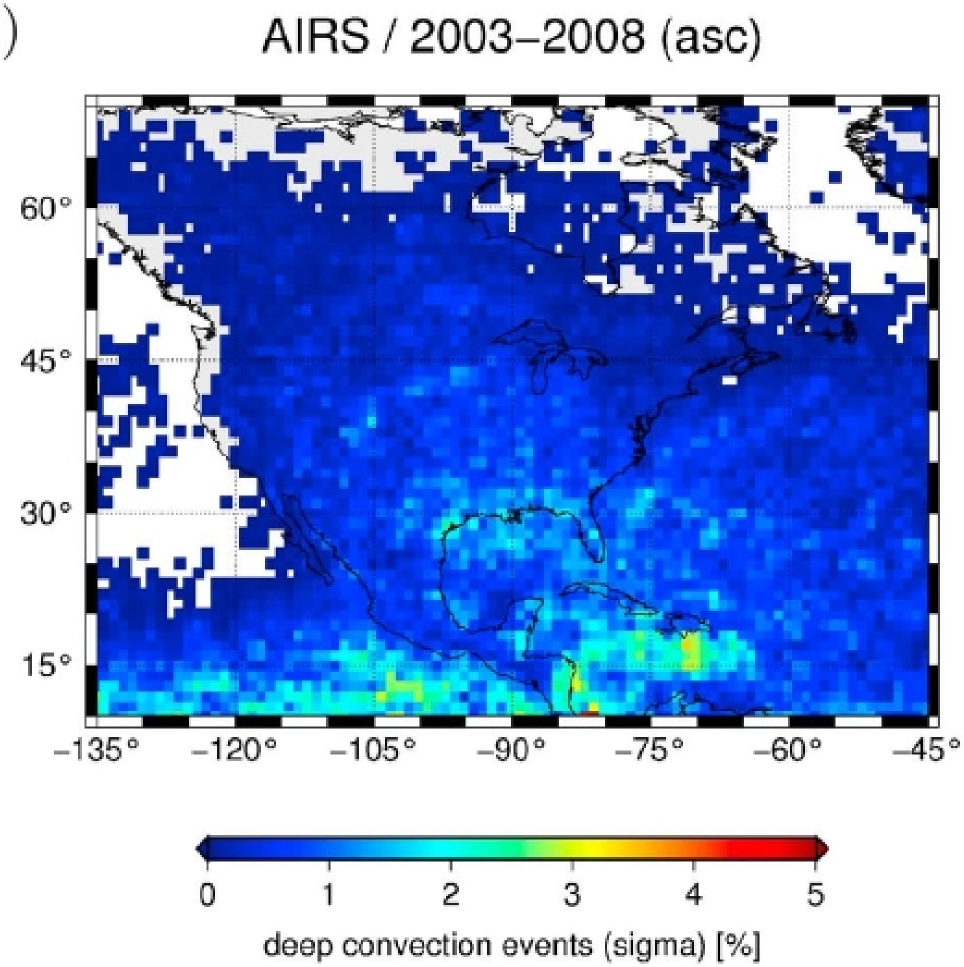
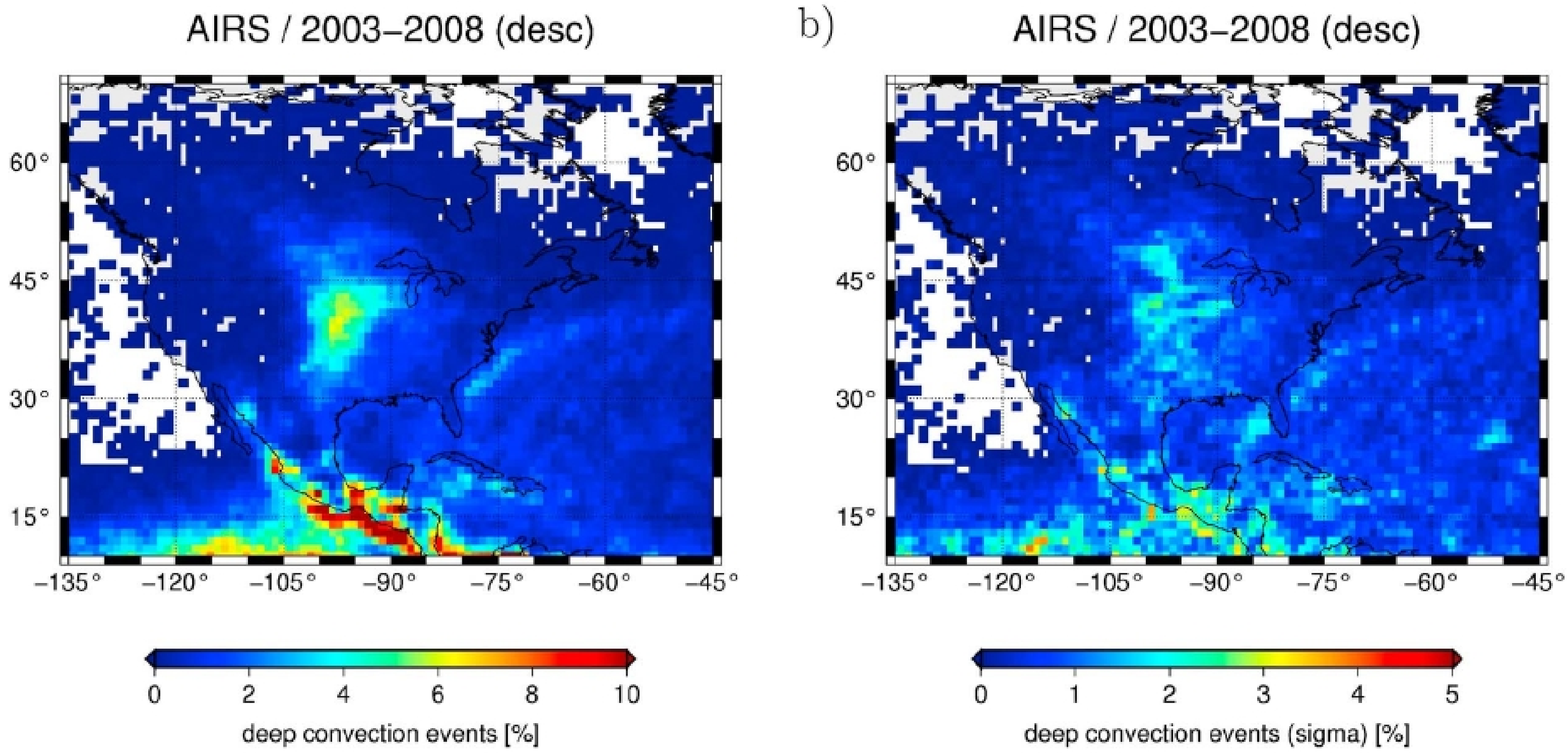


- Peaks in the tropics and subtropics ~ 6-10%
- Standard deviation in the occurrence frequency ~ 3%

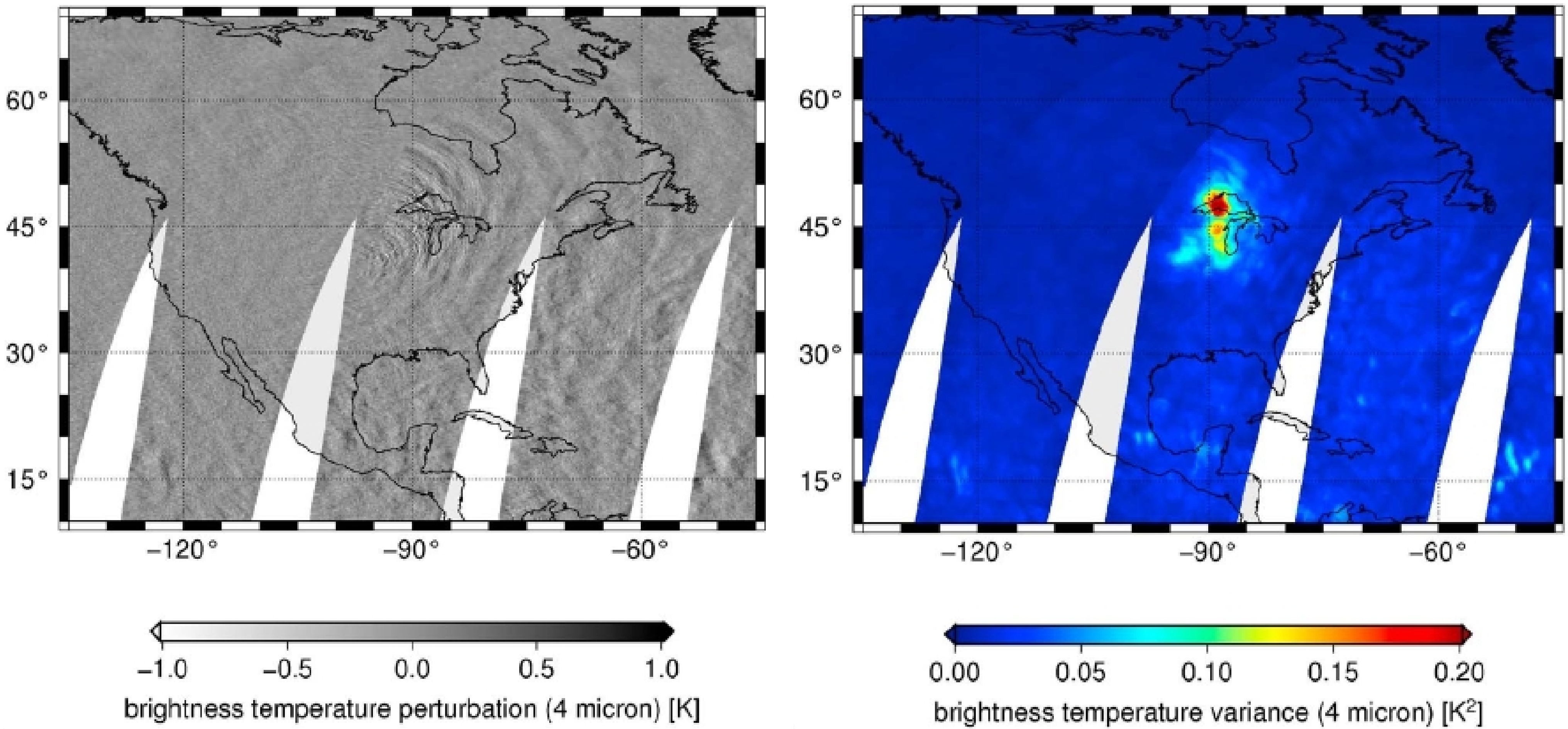
Occurrence Frequency of Deep Convection Events

- Average May-August Great Plains thunderstorm season
- Six years of data 2003-2008
- Descending data ~ 1:30am



- Second peak over northern Great Plains is pronounced in nighttime

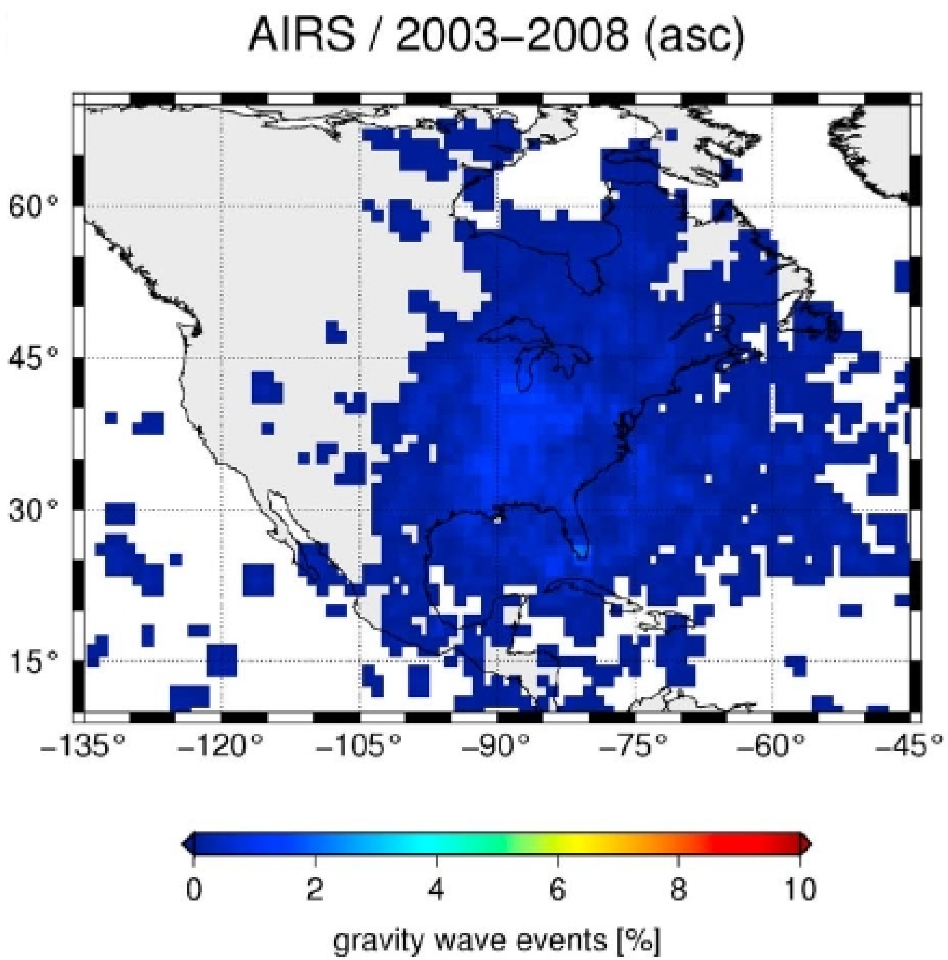
4 Micron Brightness Temperature Variance
a measure of gravity wave events

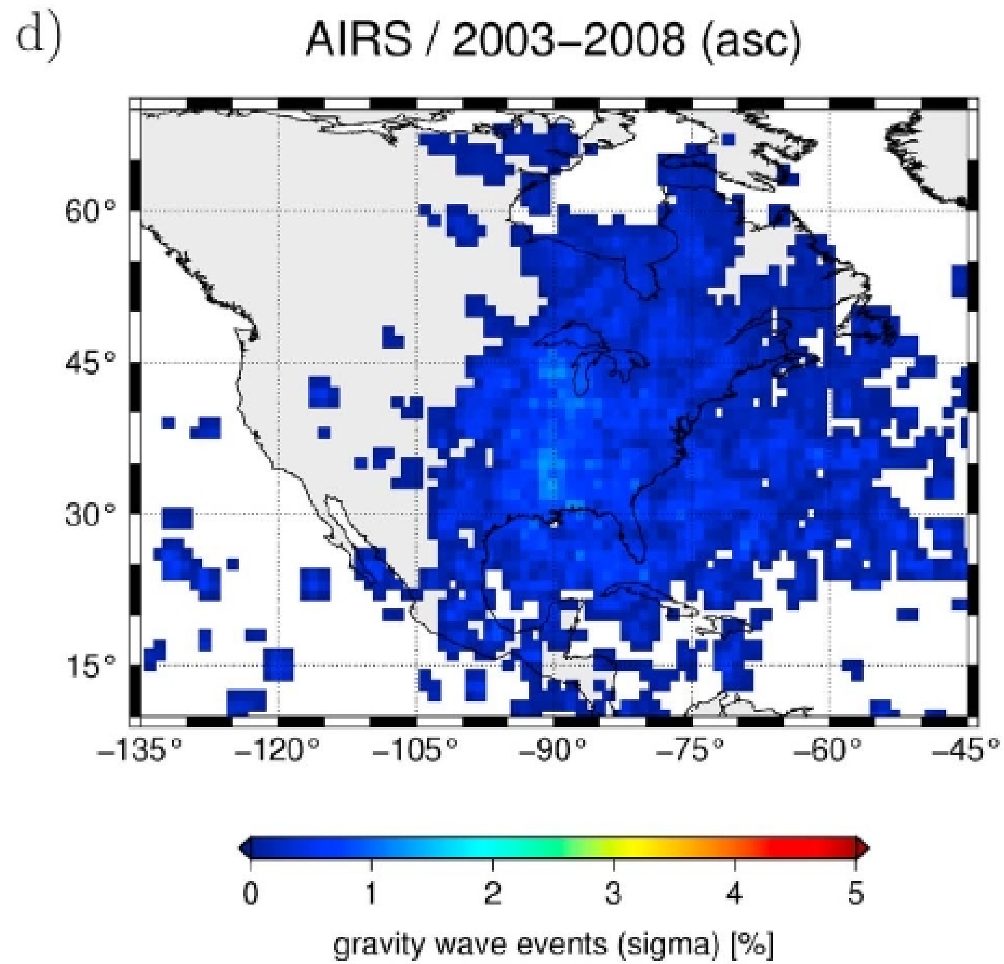


- Wave detection criterion: Variance >0.05 K^2, which is > 10 x noise
- These results are sensitive to waves with horizontal wavelengths=50-1000km, vertical wavelengths > 15km, and altitudes between 20-65km (mostly 30-40km)

Occurrence Frequency of Gravity Wave Events

- Average May-August, 2003-2008
- Ascending data ~ 1:30pm (daytime)

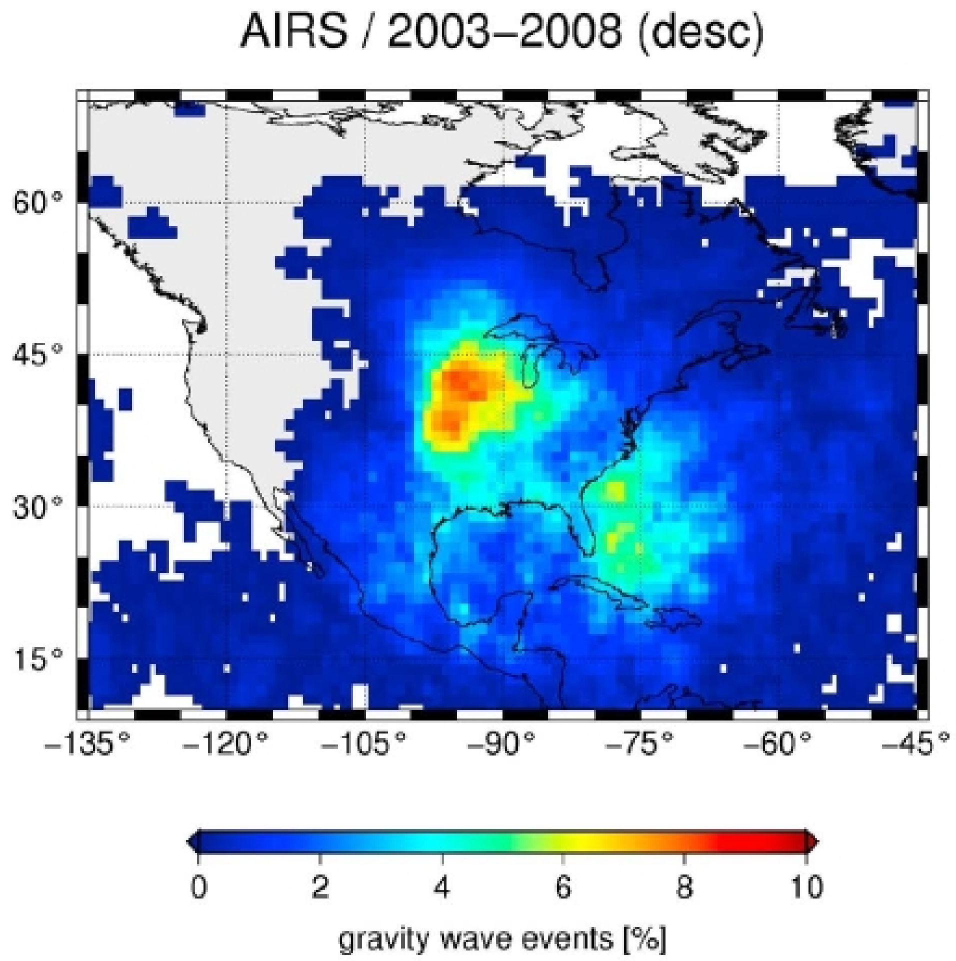




- Daytime wave occurrence frequencies are low ~1-2%

Occurrence Frequency of Gravity Wave Events

- Average May-August, 2003-2008
- Descending data ~ 1:30am (nighttime)



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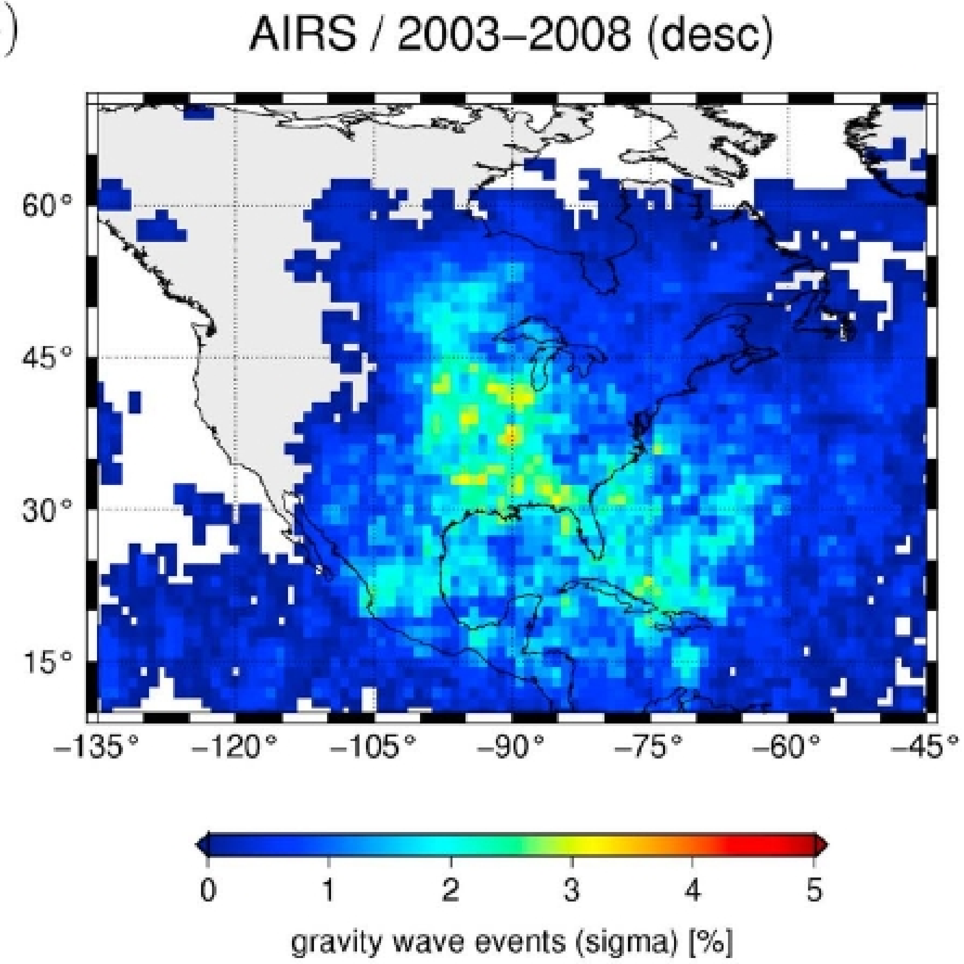


- Enhanced at night over the northern Great Plains ~8%
- Lack of events in the tropics/subtropics due to short vertical wavelengths

Gravity Wave Propagation

Group Velocity = (C_{gh}, C_{gz})

Governs the speed of the signal propagation from source to detection in the stratosphere.

From the linear dispersion relation for gravity waves with medium frequencies...

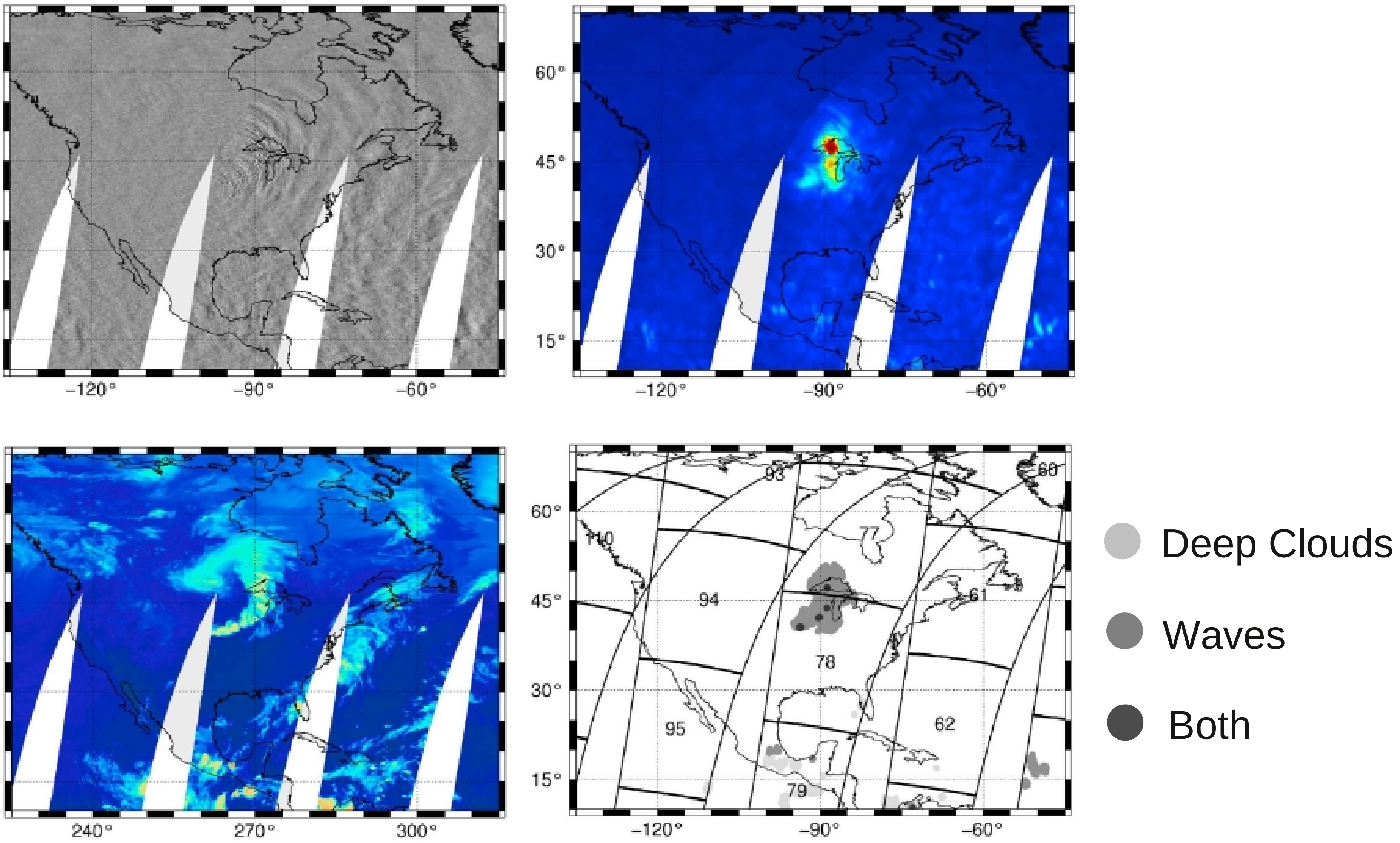
Horizontal Phase Speed, $C = C_{gh}$

Vertical Wavelength, $$\lambda_z = \frac{2\pi\left(c_{gh} - u\right)}{N}$$

Vertical Group Speed, $$c_{gz} = \frac{\lambda_z^2 N}{2\pi\lambda_h}$$

- Short horizontal wavelengths with long vertical wavelengths have rapid vertical propagation times to the stratosphere ~ 10 min – 1 hr
- Long horizontal wavelengths with short vertical wavelengths have slow vertical propagation times to the stratosphere ~ 12 hours

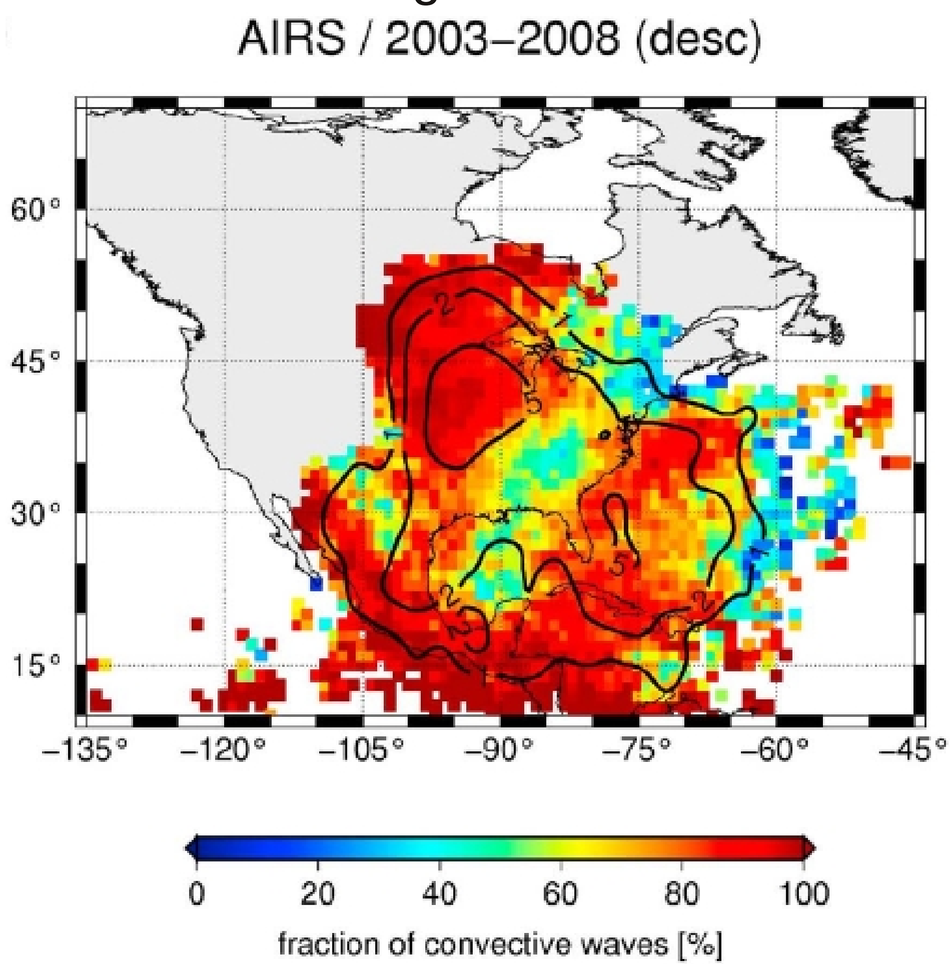
Combine cloud and wave observations to detect convectively generated gravity waves



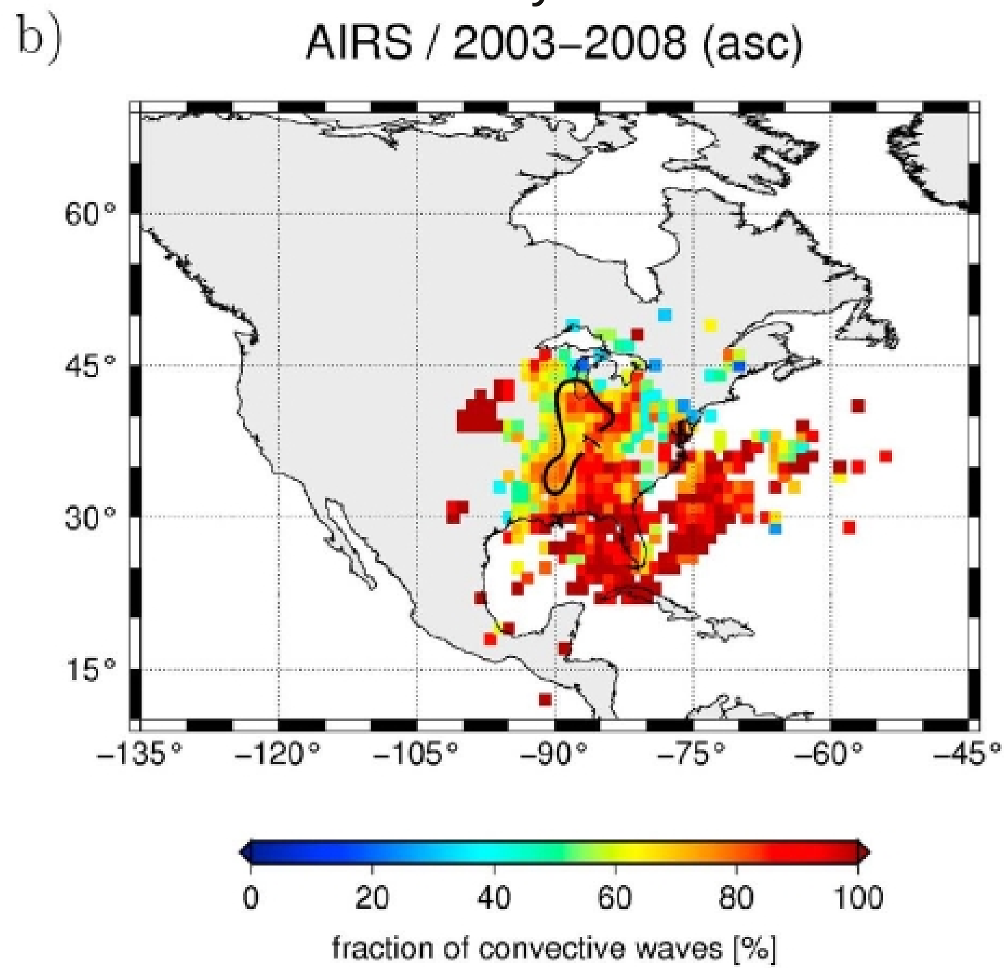
Fraction of Wave Events Associated with Convection

Search for waves within 500km of convection (some horizontal propagation)

Nighttime



Daytime

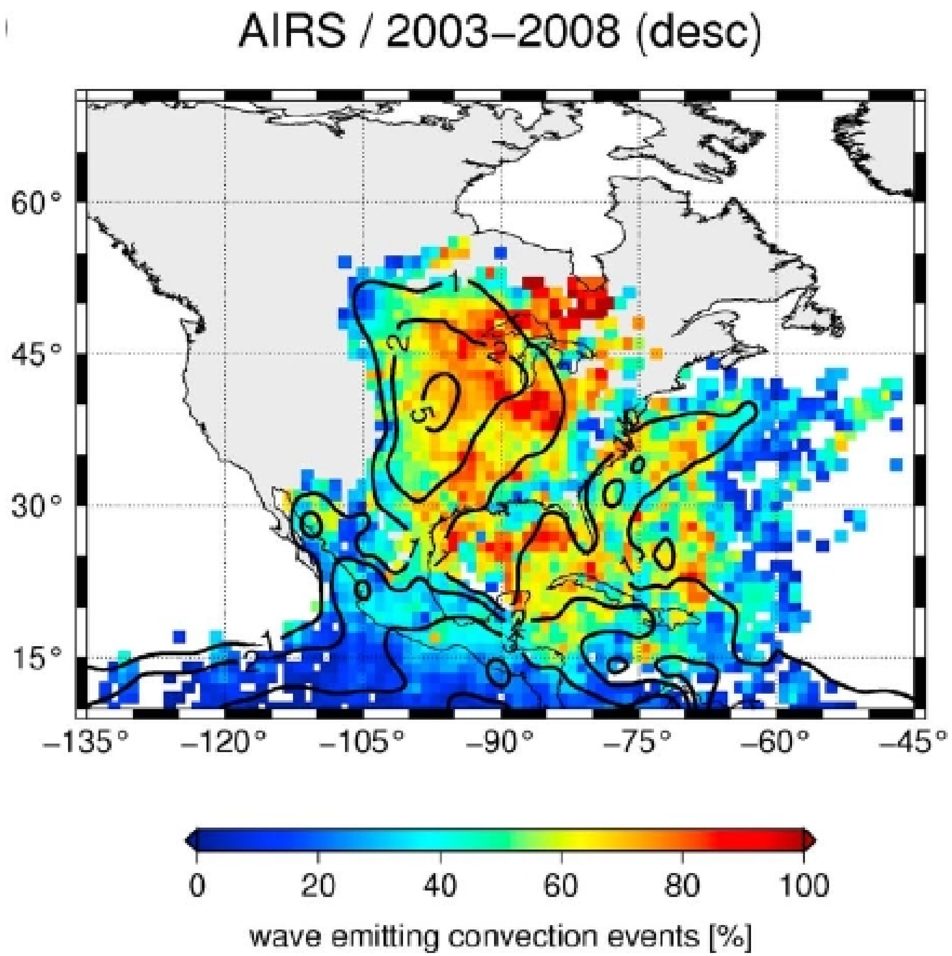


- Values highest (95%) in the nighttime midwest and Atlantic coast
- Contours show gravity wave occurrence frequencies
- High values elsewhere associated with relatively rare events

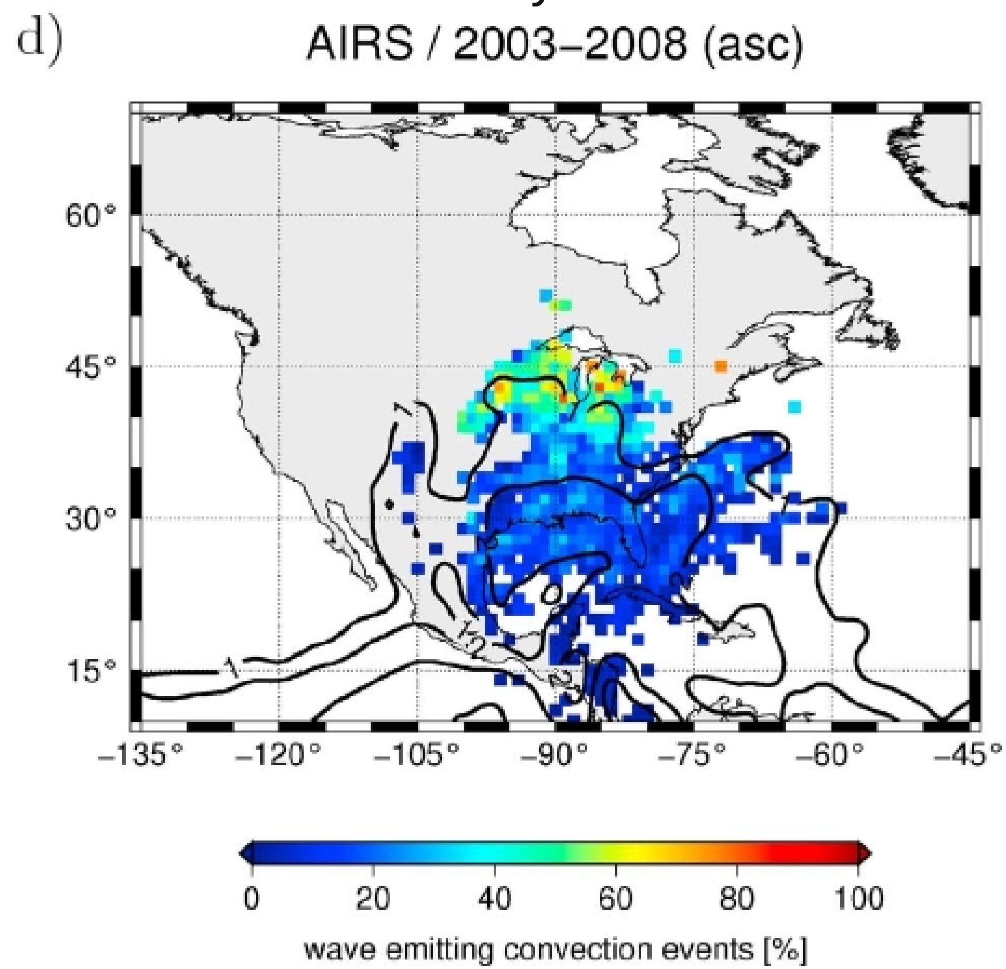
Fraction of Wave Emitting Convection Events

What fraction of deep convective events generate waves observed by AIRS?
(More relevant for validation of gravity wave parameterizations)

Nighttime



Daytime



- Maxima 90%, with large areas of the nighttime midwest > 50%
- Contours show deep convection occurrence frequencies

Summary & Conclusions

- Previously confirmed AIRS observation of convective generation of gravity waves [Grimsdell et al., 2010].

- Newest work shows midwestern thunderstorms are an important gravity wave source. Convection generates waves observed by AIRS 50-90% of the time in this region in the May-August season [Hoffmann & Alexander, 2010].

- AIRS local time sampling at 1:30 AM and 1:30 PM is an important limitation for observing waves from convection, and vertical resolution issues govern latitude variations through the influence of the background zonal wind on wave vertical wavelength.

References

Grimsdell,A. W., M. J. Alexander, P. May, and L. Hoffmann, 2010: Model Study of Waves Generated By Convection With Direct Validation via Satellite, *J. Atmos. Sci*., **67**, 1617-1631.

Hoffmann, L. and M.J. Alexander, 2010:Occurrence frequency of convective gravity waves during the North American thunderstorm season, *J. Geophys. Res.*, **115**, D20111, doi:10.1029/2010JD014401.